Hebb Repetition Effects in Visual Memory:

The Roles of Verbal Rehearsal and Distinctiveness

Neil Horton, Dennis C. Hay and Mary M. Smyth

Lancaster University

Abstract

A version of the Hebb repetition task was used with faces to explore the generality of the effect in a non-verbal domain. In the baseline condition, a series of upright faces was presented and participants asked to reconstruct the original order. Performance in this condition was compared to another in which the same stimuli were accompanied by concurrent verbal rehearsal to examine if Hebb learning is dependent on verbal processing. Baseline performance was also compared to a condition in which the same faces were presented inverted. This comparison was used to determine the importance in Hebb learning of being able to visually distinguish between the list items. The results produced classic serial position curves that were equivalent over conditions with Hebb repetition effects being in evidence only for upright faces and verbal suppression as having no effect. These findings are interpreted a posing a challenge to current models derived from verbal domain data.

The processing of serial order has been extensively investigated with a number of connectionist and mathematical models developed to explain how this is done in the context of short-term memory (STM) (e.g. Henson, 1998; Page & Norris 1998; Burgess & Hitch; 1999; Neath & Brown, 2006). However, the data on which these are built have been gathered almost exclusively from the verbal domain. It is only recently that attempts have been made to determine the domain generality of serial order processes. In a key set of experiments Smyth, Hay, Hitch & Horton, (2005) used faces in a serial reconstruction task arguing that such stimuli have well-developed encoding processes and are highly familiar making these a more accurate visual-domain analogue to words than the random matrices used in many previous studies (e.g. Avons, 1998). Smyth et al found serial position curves resembling those found in the verbal domain and similar patterns of transition errors. These were found even with concurrent verbal suppression indicating the important elements of serial order processing in STM may be general across modalities and are not a function of verbal encoding or sub-vocal rehearsal.

The longer term learning of serial order has been less extensively studied but the situation is similar in that this has been conducted almost exclusively within the verbal domain (e.g. Hebb, 1961; Melton, 1967; Cumming, Page & Norris, 2003). The methodology generally employed is derived from that used by Hebb (1961) and requires participants to perform a verbal serial recall task in which one of the lists is repeated every third trial. In comparison to the non-repeated trials, recall of the unannounced repeated list improves, producing what is termed the *Hebb repetition effect.* Recently however, there have been attempts to explore the Hebb repetition effect in other domains. For example, Page, Cumming, Norris, Hitch & McNeil (2006) explored this effect in a series of experiments that compared performance with letters and pictures presented visually. They found consistent evidence of a Hebb repetition effect across stimulus types, even under conditions of verbal suppression. Similarly, Couture & Tremblay (2006) using a derivative of the Corsi blocks task found equivalent learning rates for visuospatial dot sequences and auditory letter strings. Together, these studies challenge the accepted view of Hebb repetition effects as having a verbal basis.

The present study had two main aims; first to further examine the generality of the Hebb repetition effect within the visual domain by using human faces as stimuli. Unfamiliar faces are complex visual stimuli constructed from the same features yet give rise to an infinite number of exemplars that are difficult to verbally encode (Ellis, 1975; Smyth et al, 2005). They require both low level pattern processing and higher order encoding of the relationships for recognition (Murray 2004) and allow the exploration of serial order phenomenon in the absence of output codes or output-based rehearsal (Smyth et al, 2005). Although the existing evidence suggest that unfamiliar faces are not verbally encoded we decided to employ a verbal suppression technique to specifically determine any role that verbal rehearsal may have in producing the Hebb repetition effect with visual stimuli.

The second aim was to expand on the work of Melton (1967) who explored the conditions under which the Hebb repetition effect occurs. Using two distinct consonant sets of eight items, Melton varied the relationship between Hebb trial items and the non-repeated lists. In the similar condition, both lists were constructed from the same set and in the dissimilar condition Hebb items came from one list and the non-repeated items from the other. It was only in the latter condition that Hebb learning was found, suggesting that item distinctiveness may be crucial in determining Hebb learning. Distinctiveness has also been shown to be a key component in determining serial position function shape in short-term visual memory tasks. Hay, Smyth, Hitch & Horton (2007) used unfamiliar faces in a Sternberg (1966) probe task and found that inverted unfamiliar faces produced the previously reported flat serial position curves with last item recency (Phillips & Christie, 1977). In contrast, the same faces shown upright produced a recency gradient over the recently presented items. This pattern of results was predicted by the SIMPLE model (Neath & Brown, 2006), which is based on two forms of distinctiveness. One related to the temporal position of items and one reflecting the psychological distinctiveness of the items. Hay et al showed that under the same temporal presentation conditions, the indices of psychological distinctiveness derived by the SIMPLE model for upright and inverted faces are different and that this was responsible for the change in function shape. Our intention here is to use upright and inverted faces in a Hebb learning task to determine if changes in the distinctiveness of visual material produced similar effects to those observed by Melton (1967) in the verbal domain.

Method

Participants

Fifty-four students from Lancaster University aged between 18 to 32 years and with a mean age of 24 years, participated in this study. These were allocated at random to one of three conditions. Of the eighteen participants in the first (the baseline condition), 7 were males and 11 females, in the second (the verbal suppression condition) there were 6 males and 12 females, and in the third (the inverted face condition), 8 were males and 10 were females. All participants had normal or corrected-to-normal vision and received payment for participating in the study.

Materials and Apparatus

The stimuli consisted of 15 unfamiliar Western-European/Caucasian faces. The faces were in greyscale and standardised to a height of 100 points (approximately 1.5 inches/4cm). The faces were all male, of a similar age, with similar hair colour. The faces were selected for their visual similarity and so had only small variations in hairstyle, skin tone and face shape (see figure 1). The faces were allocated at random to form three sets of five faces (denoted as A, B & C). The face stimuli sets were rotated 180° in order to form the unfamiliar inverted face sets.

Insert Figure 1 here

All faces were presented on a white background using an Apple PowerBook G4 attached to an Iiyama 17" touch-screen display. Screen resolution was set to 1024x768 with a screen refresh of 75Hz.

Design

The three conditions employed the same presentation and response procedure described below. The first condition was the baseline condition in which upright faces were presented. To determine the role of verbal encoding in producing a Hebb repetition effect, the second condition required participants to view the same upright faces while engaging in concurrent verbal suppression. Lastly, to investigate the role of stimulus class distinctiveness on the Hebb repetition effect participants in the third condition viewed the same faces as in the baseline except that these were inverted.

Procedure

For each participant, one set of faces was denoted as the Hebb learning set; the remaining two sets of faces were denoted as the non-Hebb learning sets. Allocation of these sets was counter-balanced over participants who were presented with 18 trials. Every third trial, beginning with trial 3 (i.e. on trials 3, 6, 9, 12, 15 & 18), was a trial in which the faces from the Hebb set were repeated in the same order. Two interleaved non-Hebb learning sets appeared once each before each Hebb presentation (i.e. on trials 1, 2, 4, 5, 7, 8, 10, 11, 13, 14, 16 & 17) with the non-Hebb trial faces shown in a different random serial position on successive presentation.

Participants were tested individually and sat approximately 60cm from the computer display. For each trial, a ready signal appeared just below the centre of the display for 1 second followed 1 second later by the first in the series of five faces. All faces were presented in the centre of the display and each face was presented for 1 second with an inter-stimulus interval (ISI) of 1 second. Following the presentation of the last face in the series there was a delay of 2 seconds before the entire set of faces was re-presented in a circular array centred on the middle of the display. The location of the faces to this circular array was random for each trial. Each face was positioned in one of eight fixed spatial locations equidistant from each other.

The task describe to participants was to reconstruct the order of the items presented using the touch-screen display. Once an item had been chosen this was removed from the display so that participants were unable to amend their response. If participants were unsure of the next item in the sequence, they were instructed to guess. When all items had been selected, participants received the next trial after a gap of 1 second and no feedback was supplied.

In the baseline condition faces were presented upright with participants given no other instructions. In the condition with concurrent verbal suppression, participants were required to repeat the phrase "1,2,3,4" continuously at a rate of three words per second for the duration of the experimental run. Prior to testing, participants listened to an example recording of a female voice repeating this phrase. During the task, the experimenter monitored the pace of articulatory suppression to ensure that a suitable rate of speech was maintained. The third condition was identical in all respects to the baseline except here the faces were inverted and participants were instructed to maintain an upright head posture at all times.

Results

Each participant received two types of trial; six Hebb learning trials in which the same faces appeared in the same serial position on each presentation and twelve non-Hebb interleaved trials in which faces appeared in different serial positions on each trial. For each serial position on each trial, a participant's response was classified as correct only if the correct face was selected in the correct serial position. As there were two non-Hebb 'filler' trials, interleaved between consecutive Hebb trials, the data from these trials were averaged over serial position to form a single data point allowing easier comparison of Hebb and non-Hebb trials.

As there were 3 different Hebb face sets we explored if these produced varying Hebb repetition effects by using a mixed 3 x 6 x 2 x 5 ANOVA (Hebb face set x trial x type of trial x serial position) where Hebb face set was the between factor. This revealed no reliable differences between the sets or any interactions and so this factor was omitted from all subsequent analyses.

Hebb repetition effects and verbal suppression

To investigate whether a Hebb repetition effect is found with upright unfamiliar faces and to determine the impact of verbal suppression the data from the baseline condition were compared to that from concurrent verbal suppression condition. These were subjected to a mixed 2 x 2 x 5 x 6 ANOVA (no suppression/verbal suppression x Hebb/non-Hebb trial x serial position x trial) in which type of verbal suppression was the between factor. Although the main effect of verbal suppression approached reliability, $F(1,34) = 3.11$, $MS_e = 1.47$, $p = 0.09$, no interactions involving this factor were observed.

A reliable serial position effect was found, $F(4,136) = 9.43$, $MS_e = 0.10$, $p < 0.001$, $h^2 = 0.22$ revealing the standard bow-shaped curve with pronounced primacy and lesser recency. No interactions involving this factor were observed indicating a consistency of effect across Hebb and non-Hebb trials and across verbal suppression conditions (see Figure 2).

Insert Figure 2 here

Crucially, there was a clear advantage for repeated Hebb trials compared to non-repeated trials, $F(1,34) = 75.45$, $MS_e = 0.27$, $p < 0.001$, $h^2 = 0.69$. This main effect was modified by an interaction between type of trial and trial number, $F(5,170) = 2.81$, $MS_e = 0.21$, $p = 0.018$, $h^2 = 0.08$. Additional analyses indicated a reliable Hebb repetition effect both in the baseline condition, $F(5,85) = 3.56$, $MS_e = 0.16$, $p = 0.008$, $h^2 = 0.17$, which showed a strong linear increasing trend over trials, $F(1,17) = 14.88$, $MS_e = 0.12$, $p = 0.001$, $h^2 = 0.47$, and under conditions of verbal suppression, $F(5,85) = 3.36$, $MS_e = 0.24$, $p = 0.008$, $h^2 = 0.17$. Again a reliable linear increase over trials was found, $F(1,17) = 9.83$, $MS_e = 0.28$, $p = 0.006$, $h^2 = 0.37$.

To determine if the degree of repetition learning was influenced by verbal suppression, the number correct on each Hebb trial for each participant in both the baseline and the verbal suppression conditions was calculated. From these the gradient of the best fitting straight line was computed for each participant using the least-squares method. The gradients were subjected to ANOVA with condition as the single between factor. This indicated no reliable difference between the slopes of the baseline and the verbal suppression conditions, $F(1,34) = 0.89$, $MS_e = 0.08$, $p > 0.05$.

A similar set of analyses on the data from the non-repeating trials revealed no changes in performance over trials and no evidence of reliable linear trends (see figure 3).

Insert Figure 3 here

Hebb repetition effects with upright and inverted faces

The data from the baseline condition and the inverted face condition were subjected to a mixed 2 x 2 x 5 x 6 ANOVA (upright/inverted faces x Hebb/non-Hebb trial x serial position x trial) in which face orientation was the between factor. This revealed a main effect of serial position, $F(4,136) = 13.24$, $MS_e = 0.13$, $p < 0.001$, $h^2 = 0.28$. Standard bow-shaped curves were again observed with a strong primacy effect and a lesser recency effect on the last one or two trials. As before, no interactions involving this factor were observed indicating a consistency of effect across Hebb and non-Hebb trials irrespective of face orientation (see Figure 2).

Two other main effects were observed; better reconstruction performance with upright than inverted faces, $F(1,34) = 23.62$, $MS_e = 1.10$, $p < 0.001$, $h^2 = 0.41$, and better performance on repeated Hebb trials than on non-repeated trials, $F(1,34) = 10.56$, $MS_e = 0.37$, $p = 0.003$, $h^2 = 0.24$. More importantly, these factors were found to interact, $F(1.34) = 14.28$, $MS_e = 0.37$, $p = 0.001$, $h^2 = 0.30$. Simple main effect analyses (SME) revealed a Hebb effect with upright faces, $F(5,85) = 3.54$, $MS_e = 0.06$, $p = 0.006$, $h^2 = 0.17$, with a reliable linear component that increased over trial, $F(1,17) = 19.52$, $MS_e = 0.11$, $p < 0.001$, $h^2 = 0.53$. In contrast no Hebb repetition effect with inverted faces (see figure 3) and no evidence of any linear trend was observed. The SME analyses on the non-Hebb trials indicated that no performance changes were associated with upright or inverted faces nor were there any reliable linear trends (see figure 3).

Serial Position Effects

In order to compare the serial position effects across the three conditions the data from the non-repeating lists were compared. A 3 x 5 x 6 (baseline/verbal suppression/inverted face condition x serial position x trial) mixed ANOVA revealed a main effect of serial position effect, $F(4,204) = 13.16$, $MS_e = 0.08$, $p < 0.001$, $h^2 = 0.21$, but no reliable effect of condition, $F(1,51) = 2.61$, $MS_e = 0.86$, $p > 0.05$ and no interaction between these factors, $F(8,204) = 0.48$, $MS_e = 0.08$, $p > 0.05$. Together these indicate similar serial position patterns across the three conditions for non-repeating lists.

A further ANOVA was conducted to determine if any serial position differences were associated with repeated and non-repeated lists with inverted faces. A 2 x 5 x 6 (type of Hebb trial x serial position x trial) repeated measures ANOVA indicated that there was no reliable difference between repeated Hebb and non-repeated trials, $F(1,17) = 1.26$, $MS_e = 0.15$, $p > 0.05$, or a reliable Type of Hebb trial x serial position interaction, $F(4,68) = 0.12$, $MS_e = 0.13$, $p > 0.05$, indicating that repeated inverted face lists behave similarly to non-repeated lists.

Discussion

These results confirm the findings of Smyth et al (2005) in showing unfamiliar faces produce serial position curves similar to those obtained within the verbal domain. In addition, inverted faces, which have the same visual complexity as upright faces but do not engage the normal face processing system (Murray, 2004) also produce bow-shaped curves with considerable primacy and reduced recency indicating that the same processes for handling serial position within the context of STM are employed. In addition, performance with inverted faces is at a similar level to that with upright faces indicating that any differences cannot be due to floor effects. This observation that the serial position effects in this task do not differ depending on the nature of the stimulus material is in contrast to Hay et al (2007). However this was a probe task designed to examine short-term visual memory and did not require any encoding or use of position information. In contrast, in the current reconstruction task it is not visual memory for items that is being examined – the items were presented at response - but memory for the position of items in the list. Thus, there was little expectation of visual distinctiveness playing a major role in this task in this part of the experiment.

When considering the longer term learning of serial order, our results confirm that Hebb repetition effects are not restricted to the verbal domain. We have added to the previous findings using object pictures (Page et al, 2006) and visuospatial dot sequences (Couture & Tremblay, 2006) in demonstrating that better memory for repeated serial lists, can also be observed in the visual domain with novel faces. Importantly we have highlighted the conditions under which Hebb effects are observed by demonstrating that these are in evidence for upright faces but not when the same faces are shown inverted.

Several verbal domain models of serial learning, based on Baddeley's (1986) working memory model, suggest that visual material can be verbally encoded and rehearsed using what is known as the phonological loop (e.g. Henson1998, Page & Norris, 1998). The fact that unfamiliar faces are known to be difficult to verbally label (Ellis 1975) together with the observation here of a Hebb repetition effect under conditions of concurrent verbal suppression, demonstrates that this effect cannot be the result of verbal recoding and subvocal rehearsal. Further, our results indicate that the linear increase in performance on Hebb trials is the same irrespective of whether concurrent verbal suppression is employed. This is similar to the Page et al (2006) result in the verbal domain with letters (Expt. 1) and extends their work with object pictures where their design did not allow a comparison between a baseline and a concurrent verbal suppression condition to be made. These results are also problematic for models that suggest the Hebb effect is due to other forms of rehearsal (e.g. Burgess & Hitch, 1999) or output processes (e.g. Cohen & Johansson, 1967) as unfamiliar faces have no direct access to an output system and do not allow rehearsal via any known internal analogue (Smyth et al 2005).

Although there is considerable divergence among researchers as to what underpins the

Hebb repetition effect (Couture & Tremblay, 2006), the present results together with the work of Melton (1967) have identified one necessary factor. That is item visual distinctiveness. Hay et al (2007) have already demonstrated that inverted faces have lower function power indices in the functions produced by the SIMPLE model. These in turn, are hypothesised to reflect differences in item distinctiveness (Neath & Bower, 2006). However, since distinctiveness can be a nebulous concept, Hay et al (2007) attempted to specify what this meant for the upright and inverted faces used in their short-term visual memory task.

They found that in a short-term visual memory (STVM) probe task using upright and inverted faces the latter had higher values of psychological distinctiveness calculated using the SIMPLE model (Neath & Brown, 2006). They suggest that this reflects the existing mechanisms for encoding and storing faces within an existing multidimensional space whose dimensions have developed to best discriminate exemplars (Valentine 1991). This is not true for inverted faces. These have probably never been previously encountered and consequently have a representational space that is minimally populated with dimensions that have yet to be sufficiently determined. Both of these change as a result of perceptual learning which has been shown to be accompanied by increases in both memory and perceptual sensitivity (Palmeri, Wong & Gauthier, 2004). The current observation of a Hebb repetition effect only with upright faces indicates that the ability to encode list exemplars distinctively may be crucial. This link between distinctiveness and the observation of a Hebb repetition effect has also been found within the verbal domain. Melton (1967) reported a series of experiments using consonants where the distinctiveness of the items in the repeated lists and the non-repeated lists was systematically varied. In one condition, all lists were constructed from the same nine consonants while in the other the repeated and the non-repeated lists were constructed from different consonant sets. Only when the repeated lists were distinctive from non-repeated lists was a Hebb effect observed.

In conclusion, studies in domains other than the verbal provide useful insights for those modelling the short and longer term processing of serial order. The similarities between the results with verbal and visuospatial studies, suggests some common underlying processes. If so, this poses difficulties for many of the existing computational models, which now appear too domain specific and invoke explanatory mechanisms that do not obviously generalise to other domains.

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